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SOME RESULTS OF THE DEVELOPMENT AND INVESTIGATION OF INSTRUMENTS FOR MONITORING THE CARDIOVASCULAR SYSTEM

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ABSTRACT: A set of electronic instruments developed to study the heart, and to obtain more correct information on the functioning of the heart, is discussed. Included are a blood analyzer, an instrument for studying the blood coagulation process, an automatic sphygmomanometer, and an electromagnetic blood flow meter.

Despite tremendous medical successes to date, cardiovascular disease still is one of medicine's important problems. /190*

The human heart and circulatory system is a complicated, closed system consisting of pumps that transfer the blood and that are capable of changing their operating characteristics, elastic reservoirs, and branch transmission lines. The characteristics of each component are not simply determined by the functioning of adjacent sections of the system. Thanks to nervous regulation, the functioning of any one element is a function of events occurring in outlying sections of the system, and even of events taking place outside the system.

This complexity of relationships explains why the functioning of the heart and of the vessels has not yet been adequately studied.

A set of electronic instruments was developed in order to study the functions of the heart, and to obtain more correct information that would include the above factors. These instruments make possible discrete, as well as continuous, measurements of such important physiological functions of the body as analysis of the blood for erythrocytes and the hematocrit index, analysis of the coagulability of the blood, blood pressure, pulse (the heart rate), and the blood flow rate.

Electronic Erythrocyte Analyzer and the Hematocrit Index

Determination of the hematocrit number is widespread in clinics and in experiments because it can be used to judge changes in the ratio of plasma and erythrocytes. This is particularly necessary in the treatment of burn victims when, in the case of widespread burns, the question arises of the infusion of great quantities of fluid, as well as after heavy loss of blood when the decision as to the infusion of different blood components must be made.

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* Numbers in the margin indicate pagination in the foreign text.

The lack of simple methods for establishing the hematocrit number is an obstacle in the path of its widespread determination among the ill.

The building of the blood analyzer, permitting a more accurate, and more importantly, a more rapid counting of particles and determination of the hematocrit, is one of the tasks of general blood analysis that can be accomplished by the electrical conductivity method.

The electrical resistance of the blood depends primarily on its erythocyte content, because the influence of leucocytes and thrombocytes on conductivity /191 is less than 1 percent.

We investigated the conductivity of the blood in order to build an electronic erythocyte analyzer.

The investigations were made with a converter consisting of a chamber (plexiglass) with platinum electrodes. Platinum electrodes are more suitable for experiments at frequencies of from 0 to 20 kHz because their eigenpotential is constant.

The selection of the shape of the measuring chamber (of the cell) and the design of the electrodes, is significant when investigating blood conductivity. The difficulty caused by blood settling in the measuring cells, and in filling and cleaning the cells, led to the need to select cells experimentally. The best results were obtained with a cell with a rectangular cross section and the platinum electrodes secured to the sides.

The investigations of blood conductivity were conducted using the arrangement shown in Figure 1.

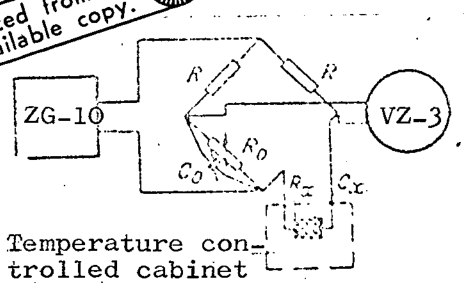


Figure 1. Schematic diagram of the measurement of electrical conductivity of blood.

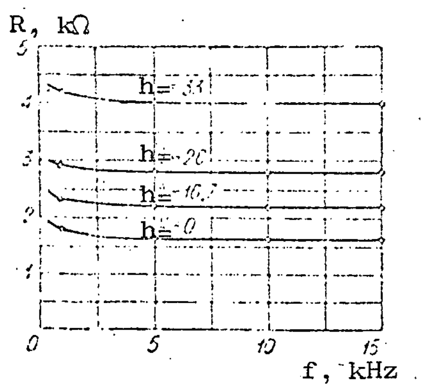


Figure 2. Resistance of plasma and of blood with different hematocrit indices in terms of frequency.

The donor's blood sample was carefully centrifuged to separate the plasma from the erythocytes. The plasma thus separated from the healthy blood was placed in the measuring cell.

Numerous measurements of the resistance of plasma from different blood samples with t^{O} = constant (the measuring cell was placed in a temperature controlled cabinet) revealed that variations in the resistance of plasma from different individuals was slight.

Figure 2 shows the resistance of plasma and of blood with different hematocrit indices in terms of the frequency.

What follows from the curves in Figure 2 is that a high hematocrit (the /19 ratio of the volume of suspended blood elements to the volume of blood) means higher blood resistance, and that the resistance remains constant, beginning at f = 5 kHz. The increase in resistance with decrease in frequency is caused by polarization phenomena. Consequently, erythocytes can be considered as nonconducting corpuscles in the audio frequency region.

The investigations revealed that temperature coefficients decreased with rise in temperature, and had the same value for plasma as for blood at a predetermined temperature.

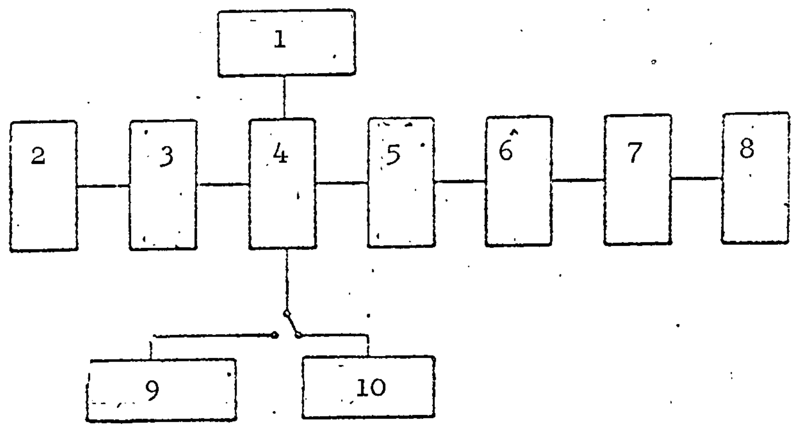
A series of solutions were made up with different concentrations of corpuscles in human blood plasma for purposes of obtaining a quantitative relationship between conductivity and the number of erythocytes.

The red corpuscles in each series were counted using two calibrated chambers and three calibrated pipettes, providing six determinations in all for each blood sample. The conductivity of the plasma, and of the whole blood, in each solution was determined at the same time.

The results confirmed the presence of a quantitative relationship between the ratio of conductivity and the number of red corpuscles.

These results agree with Wagner's data [1], obtained for a dielectric with a heterogeneous structure and based on Maxwell's theory [2].

We used the results to develop an experimental model of a blood analyzer. The analyzer, the block schematic of which is shown in Figure 3, is designed for rapid determination of the number of red blood corpuscles. The method of determining the relative volumetric concentration of erythocytes in the blood is based on measuring the conductivity of a blood sample in a Wien bridge.



1- Temperature compensator 2- Generator 3- Emitter follower
4- Bridge 5- Emitter follower
6- Amplifier 7- Detector 8- Meter
9- Calibration resistance 10- Blood sample

Figure 3. Block schematic of the analyzer.

The instrument pickup is a pipette made of plexiglass with internally mounted platinum electrodes. A blood sample with a volume $V = 20\ mm^3$ is placed in the space between the electrodes. The use of plexiglass allows one to watch the filling of the space between the electrodes with the sample.

Tests made using the electronic blood analyzer provided the basic technical characteristics of the analyzer and made it possible to use it to analyze blood composition.

Instrument error, when measuring the number of erythocytes, is ±5 percent.

An Instrument for Studying the Blood Coagulation Process

Knowledge of the blood coagulation mechanism is necessary for an understanding of the nature of many pathological states of the human body associated with the rise and fall of the coagulability of the blood, as well as for the development of rational and monitored methods of treating, and preventing, many diseases.

The blood coagulation process comprises several closely interrelated phases, but as many investigators have shown, the principal phases of coagulation are three successive ones [3]: the formation of an active thromboplastin, the formation of thrombin, and the formation of fibrin.

Once the clot is formed it begins to contract, and the blood coagulation process is completed, but the clot can be subject to lysis to a greater or lesser degree.

There are many pathological conditions when clotting time, clot density, and liquefaction (dissolving) time will be different. This helps in making the diagnosis, because the results of coagulation of the blood are decisive in diagnostic work. /194

The instrument, developed at the Tomsk Polytechnical Institute, can be used to measure the blood coagulation rate and the protein fractions, as well as to determine the clot retraction rate, with automatic recording of the process.

The instrument is based on the photometry principle, in that indications of changes in the blood coagulation process are based on the relationship between the degree of absorption of the light flux and the phase of blood coagulation.

The diagrammatic arrangement of the instrument is shown in Figure 4.

Spectral analysis of coagulating blood in a spectrophotometer has revealed that the maximum for the transmitted rays is in the red (a wavelength of from 0.55 to 0.65 microns).

An FS-A1 photoresistance, which has a suitable frequency characteristic curve and a linear section on the spectral characteristic curve, is used as the sensitive element in the instrument's pickup.

The method developed at the Tomsk Polytechnical Institute reveals upsets in blood coagulation for different body conditions more precisely than other methods.

This instrument is simple in design, small in size, and light in weight. It can be used to provide automatic recording of up to 12 blood samples (the time to check 12 samples is 12 to 24 seconds).

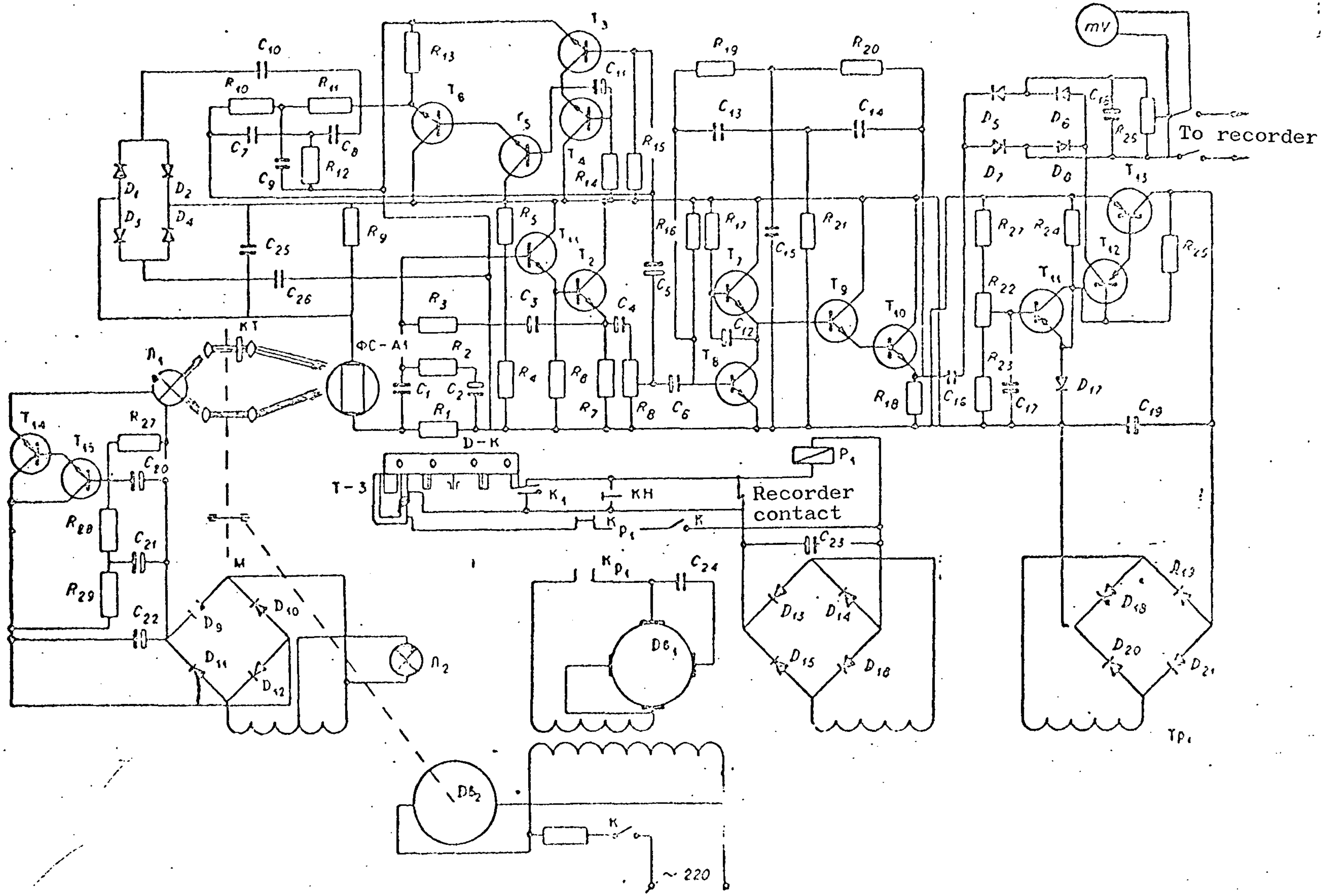


Figure 4. Diagrammatic arrangement of the instrument for determining the blood coagulation process.

Maximum instrument error is ±3 percent. The instrument can be used in the laboratories of treatment and prevention institutes, in clinics, and in scientific research institutes, to diagnose and treat many diseases.

Automatic Sphygmomanometer

Blood pressure, frequency of heart contractions, and body temperature are the magnitudes most often measured in medical practice. Determination of maximum and minimum blood pressure levels during each cardiac cycle, in combination with diagnostic data, provide valuable information on the functions of the vessels and on heart action.

Today, there are different methods in use to monitor the rapidly occurring reactions of blood circulation, but they can be used only in special cases because to observe treatment with instruments is usually complicated and takes a lot of time.

An instrument suitable for clinical research must be simple in design, and must also be simple to use. The Tomsk Polytechnical Institute has developed an automatic sphygmomanometer that measures the blood pressure at the wall of the vessel, and simultaneously records the frequency of heart contractions.

The instrument's operating principle is based on the use of the conventional cuff method and the measurement of the Korotkov tones occurring at the peripheral outlet of the artery, in the ulnar flexure.

The instrument's electronic circuit, Figure 5, consists of an amplifier and a former. The former controls the electronic key and is a component part of the integral needle-type frequency meter. The electronic key controls a relay that fixes the manometer needle to show the diastolic pressure. The systolic pressure is fixed at the time of arrival of the first Korotkov tone. The blocking circuit disconnects the former after the Korotkov tones are fixed.

An unbalanced bridge is used in the electrical thermometer. A microphone /195
is used as the sensitive element for the pickup reproducing the Korotkov tones.

This instrument, which has a self-contained power supply and is small in size, can measure pressure from 30 to 300 mm Hg, frequency of heart contractions from 0 to 250 per minute, and body temperature from 35 to 42°C.

The instrument combining as it does the features of automatic pressure measurement, an electronic thermometer, and a pulse frequency meter, can be used

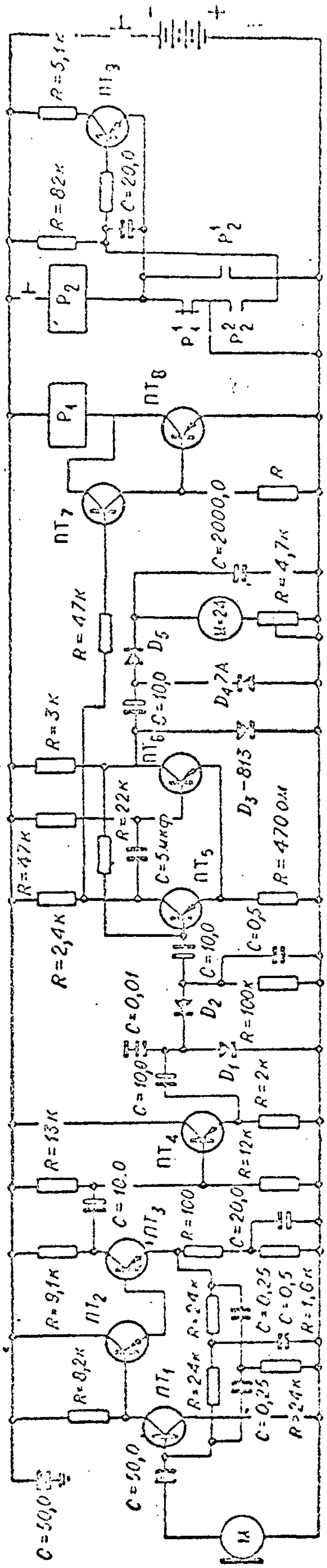


Figure 5. Principal schematic diagram of the automatic sphygomomanometer.

in clinics to observe the seriously ill, as well as in the receiving and diagnosis sections.

Electromagnetic Blood Flow Meter

Continuous recording of the blood flow rate provides a means for evaluating the effectiveness of the various stimulating and inhibiting factors acting on the secretory functions without resorting to complicated chemical research. This research is needed to solve pharmacological problems, as well as when engaged in experimental pathology. This type of information can be obtained by using an electromagnetic blood flow rate converter [4].

The principle of operation of the electromagnetic flow meter is widely known, and involves the fact that when a wire is moved in a magnetic field in a direction perpendicular to the wire and to the magnetic lines of force there will be induced in the wire an electromotive force the magnitude of which is directly proportional to the number of lines of force cut by the wire in unit time.

If the magnetic flux density, and the diameter of the vessel, are constants, the potential generated at the electrodes will be a linear function of the flow rate.

The electrodes must be placed on the surface of the tube wall in order to measure the electromotive force induced in electrodes in nonconducting tubes (the pick-up of a cannula type blood flow meter, for example). In the case of flow through the tube with nonconducting walls, such as those of blood vessels, the potential induced by the flow can be measured by placing the electrodes on the outside wall of the vessel.

Essential for proper operation of the electromagnetic flow meter is provision of maximum homogeneity of the magnetic field, otherwise the signal at the converter electrodes will depend on the profile of the distribution of the flow rate at the vessel cross section [5]. /196

A homogeneous magnetic field must be created in the gap between the electrodes when the magnetic circuit is tiny, as in the case of instruments designed for implantation in the body of an animal, where excess weight and size of the converter can prevent taking measurements, but the readings depend on the flow profile when the field is inhomogeneous.

There are four types of magnetic systems widely used in the development of miniature electromagnetic blood flow meters designed for continuous experimental investigations: a C-shaped magnetic circuit; an interrupted magnetic circuit of the solenoid type; a single-coil converter; and a double-coil converter.

The first two types of magnetic converters can be used for vessels 1 to 5 mm in diameter, the latter two for those from 1 cm up.

Studies made of the magnetic field in the working air gap of the converter, using such methods as solid models, electrolytic baths, and test coils, show good convergence of results for magnets with the same shape as pole tips.

We were able to broaden the zone of the homogeneous field in the working gap of a C-shaped magnetic circuit by a factor of 1.5 as compared to flat poles, and by a factor of 1.25 as compared to U-shaped poles, by using poles with correcting heads.

Our research developed a relationship between the dimensions of the C-shaped magnetic circuit and the homogeneous magnetic field.

The optimum variant of the flow meter magnet can be obtained when the following relationships are observed:

$$B_1 \geq \delta_0;\ \delta_0 = h;\ b = 0.44\ B_1 \text{ and } l = 0.6L,$$

where

B_1 is the distance between the pole and the yoke of the electromagnet;

δ_0 is the magnitude of the air gap between the poles;

L is the length of the pole of the electromagnet;

h is the height of the volume of the homogeneous field in the gap between the poles;

b is the width of the volume of the homogeneous field in the gap between the poles;

l is the length of the volume of the homogeneous field in the gap between the poles.

This procedure for making the calculation for the C-shaped electromagnet [6] also can be used for other magnetic systems. Then the calculation for the magnetizing ampere-turns includes the magnetic leakage factor, determined experimentally for each shape of magnetic circuit.

The leakage factor, σ_n, for the C-shaped magnet increases with increase in the working air gap, δ_0. The increase in σ_n with increase in δ_0 is caused by the increase in the stray flux, Φ_S.

Investigations made of the double-coil converter provided experimental relationships connecting the dimensions of the supply windings of the converter with the homogeneous field. It was found that the zone of the homogeneous field in the double-coil converter can be expanded by reducing the distance between the ends of the coil (reducing angle φ), as well as by increasing the distance between the coil arms, a. /197

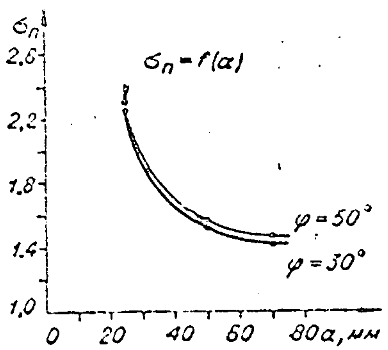


Figure 6. The leakage factor, σ_n, in terms of the parameters a, and φ, for a double-coil converter.

Figure 6 shows the leakage factor in terms of a for different φ. The value of σ_n decreases with increase in a because of the increase in the working flux.

These investigations of magnetic systems have made it possible to obtain the necessary geometric parameters for the magnet, as well as the leakage factor for the system, in each concrete case. The magnetic systems described can be used in struments for measuring blood flow rates incorporating a selective semiconductor measuring circuit.

Widespread use in medicine of the set of instruments described will make it possible, for example, to obtain answers to such vitally important questions as those involving the conditions needed to create the prerequisites for heart stoppage, and the cause of spasms. The answers to many questions of hemodynamics and hematology will help arm practical medicine with reliable, scientifically based methods for treating, as well as preventing, cardiovascular diseases.

REFERENCES

1. Wagner, K., Arch. Electrotechnik. 1914, p. 2.

2. Maxwell, J., Treatise on Electrocity and Magnetism, Oxford University Press, Cambridge, England, 1873.

3. Balluzha, V. P., Malyarovskiy, V. N., Oyvin, I. A., Laboratornyye metody issledovaniya svertyvayushchey sistemy krovi [Laboratory Methods of Investigating the Blood's Coagulating System], GIML, Moscow, 1962.

4. Krayev, I. N., "Selection of a Blood Flow Meter," Sb. mater. Vsesoyuznoy mezhvuzovskoy konf. po metodam i priboram dlya izmereniya raskhodov zhidkostey, gazov, i sypychikh materialov [Collection of materials from the All-Union Inter-VUZ Conference on Methods and Instruments for Measuring the Flow Rates of Fluids, Gases, and Bulk Materials], Tomsk, 1966.

5. Korsunskiy, L. M. Elektromagnitnyye gidrometricheskiye pribory [Electromagnetic Hydrometric Instruments], Moscow, 1964.

6. Krayev, I. N., "Calculation for the Magnetic Systems of Electromagnetic Blood Flow Meters," Sb. mater. Vsesoyuznoy mezhvuzovskoy konf. po metodam i priboram dlya izmereniya raskhodov zhidkostey, gazov, i sypychikh materialov [Collection of materials from the All-Union Inter-VUZ Conference on Methods and Instruments for Measuring the Flow Rates of Fluids, Gases, and Bulk Materials], Tomsk, 1966.